Enclosure 3 to TN E-25513

Transnuclear, Inc. Calculation 10421-010, Revision 1 (Non-proprietary version)

TRANSNUCLEAR AN AREVA COMPANY	# Calculation Cover Sheet	Calculation No.: 10421-010 Revision No.: 1 Page: 1 of 33

DCR NO: 10421-2	**PROJECT NAME:** TN-40 Transport Package
PROJECT NO: 10421	**CLIENT:** Transnuclear, Inc.

CALCULATION TITLE:

Thermal Analysis for TN-40 Transport Cask, Normal Transport Conditions

SUMMARY DESCRIPTION:

This Calculation determines the maximum component temperatures and temperature profiles of TN-40 Transport Cask for thermal and structural evaluation for normal transport conditions

If original issue, is licensing review per TIP 3.5 required? N/A

Yes ☐ **No** ☐ **(explain below)** **Licensing Review No.:** N/A

Software Utilized:	**Version:**	**Number of CDs:**
ANSYS	8.0 and 8.1	3

Calculation is complete: Originator Signature:	Date: 06/13/06
Calculation has been checked for consistency, completeness and correctness: Checker Signature:	Date: 06/14/06
Calculation is approved for use: Project Engineer Signature:	08/07/2006 Date:

REVISION SUMMARY

REV.	DATE	DESCRIPTION	AFFECTED PAGES	AFFECTED DISKS
0	09/19/05	Initial Issue	All	All
1	~~06/13/06~~ 08/07/06	Correction of editorial comments and adding the maximum accessible temperature without personnel barrier	5 to 9, 16-24, and 27	Disc 3 is added

TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

Page

1.0 PURPOSE

Determine the temperature distribution and the maximum component temperatures for normal transport conditions at 100° F and -20° F ambient temperatures and determine the temperature profile at -40°F ambient to evaluate the maximum thermal stresses.

2.0 REFERENCES

1. Calculation 1042-18, rev.1, "Off-Normal Thermal Analysis for TN-40 Storage Cask"
2. Calculation 10421-9, rev. 1, "Effective Fuel Properties for 14x14 Assembly in TN-40 Cask"
3. TN-40 Transport Cask Drawings 10421-71-1 to 10421-71-10, rev. 0.
4. Viebrock, "Domestic Light Water Reactor Fuel Design Evolution", Vol. III, Nuclear Assurance Corporation, 1981
5. TN-40 Transport Packaging Configuration, Drawings 10421-71-40 to 10421-71-44, Rev. 0
6. ASME Boiler and Pressure Vessel Code, Section II, Part D, "Material Properties", 1989
7. Code of Federal Regulations, Part 71, "Packaging and Transportation of Radioactive Material", 10 CFR 71, 2003
8. Siegel, Howell, "Thermal Radiation Heat Transfer", 4th Edition, 2002
9. Safety Analysis Report for TN-68 Transport Package, rev. 4, CoC 71-9293
10. U.S. Department of Agriculture, Forest Service, "Wood Handbook: Wood as an Engineering Material"
11. NUREG/CR-0200, Vol.3, Rev. 6, SCALE, A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation
12. USNRC, SFPO, "Cladding Considerations for the Transportation and Storage of Spend Fuel", Interim Staff Guidance ISG-11, Rev. 3
13. Rohsenow, Hartnett, Cho, "Handbook of Heat Transfer", 3rd Edition, 1998
14. ANSYS Computer Code and User's Manuals, Rev. 8.0 and 8.1
15. Response to the First RAI for the model TN-68 Transport Package Application, Docket 71-9293, question 3-6.
16. Perry, Chilton, "Chemical Engineers' Handbook", 5th Edition, 1973
17. NUHOMS® - MP197 Multi-Purpose Cask, Transportation Package, Safety Analysis Report, Rev. 4
18. Rohsenow, Hartnett, "Handbook of Heat Transfer Fundamentals", 2nd Edition, 1985
19. Design Criteria Specification (DCS) for the Transport of the TN-40 Dry Storage, 10421-0101, Rev.0

3.0 METHODOLOGY

A three dimensional finite element model of the TN-40 transport cask is developed using ANSYS code [14]. The model is 90 degree symmetric and considers the upper quarter of the cask. The geometry of the cask model includes the impact limiters, trunnions, cask shells, cask bottom plate, cask lid, basket, and fuel assemblies.

All dimensions of the model correspond to nominal values defined in the cask drawings [3]. All cask components including the gaps are modeled using SOLID70 conducting elements.

Figure 3-1 through Figure 3-7 show the details of the finite element model. The contact gaps between the basket components as well as gaps between the cask and the impact limiters are discussed in Section 4.

The fuel assemblies are modeled as homogenized regions within the fuel compartments. The thermal properties for the homogenized fuel are calculated in [2].

The material properties used in the model are described in section 5 and correspond to values in ASME code [6]. Thermal properties of wood are listed in Section 6.

The SOILD70 elements representing the homogenized fuel are given heat generating boundary conditions in the region of the active fuel length. Active fuel length is considered to be 144" beginning at about 4.0" above the bottom of the fuel assembly. Fuel assembly has a total length of 152" in the model. The fuel data corresponds to the values reported in reference [4].

The axial decay heat profile for the fuel assemblies are identical to that for the storage conditions as defined in reference [1] with a maximum peaking factor of 1.2. The peaking factors are shown in Table 3-1.

[redacted]

The maximum decay heat load of 22 kW is conservatively used in the analysis (Note the total cask decay heat is limited to 21 kW in [19]). The decay heat load is considered uniformly distributed over 40 assemblies. This gives a heat load of 0.55 kW per assembly. The heat generating rate for each region of the active fuel is calculated as follows:

[redacted] $\times$ [redacted]

[redacted]

Proprietary Information Withheld in accordance with 10 CFR 2.390.

Convection and radiation to the ambient are combined together in form of total heat transfer coefficient, which is defined as a temperature dependent material property in the model. The total heat transfer coefficient is used to apply the boundary conditions on the outer surface of the cask. Appendix B describes the correlations to calculate the total heat transfer coefficients.

Solar radiation is considered as a constant heat flux applied on the SURF152 elements overlaid on the outer surface of the transfer cask. The amount of the solar heat flux over a 12-hour solar day defined in reference [7] is averaged over a 24 hour period to calculate the solar heat flux. The averaged solar heat flux is considered as the maximum amount of solar radiation that is available for absorption on any surface. This value is multiplied by the absorptivity factor of the packaging (cask and impact limiters) outer surfaces to calculate the amount of solar heat flux that each surface absorbs.

The outer surfaces of the cask and the impact limiters are painted white. Reference [8] gives an emissivity between 0.92 and 0.96 and a solar absorptivity between 0.09 and 0.23 for white paints. To account for dust and dirt and to bound the problem, the thermal analysis uses a solar absorptivity of 0.3 and an emissivity of 0.9 for the white painted surfaces.

The solar heat flux values applied in the model are listed below.

Surface shape	Insolance [7] (gcal/cm^2)	Total solar heat flux average over 24 hours (Btu/hr-in^2)	Absorptivity	Solar heat flux in the model (Btu/hr-in^2)
Curved, Painted	400	0.427	0.3	0.128
Flat, Vertical, Painted	200	0.213	0.3	0.064

Boundary conditions at 100 °F and solar heat fluxes from the above table are applied in the model to bound the maximum component temperature for transport operation. To maximize the thermal stress, no solar heat flux is considered for ambient temperatures of -20 °F and -40 °F.

TN-40 cask uses a personnel barrier to limit the accessibility of the hot cask surface (Drawing 10421-71-40, rev. 0, [5]). The accessible surfaces of the TN-40 transport cask consist of the personnel barrier and outermost vertical and radial surfaces of the impact limiters. The cask body model is run without insolance to determine the accessible surface temperature of the impact limiters in the shade. The personnel barrier surrounds approximately one fourth of the cask body and has an open area of at least 80%. Boundary conditions at 100 °F and no insolance are considered to calculate the maximum accessible temperature under shade.

Proprietary Information Withheld in accordance with 10 CFR 2.390.

Proprietary Information Withheld in accordance with 10 CFR 2.390.

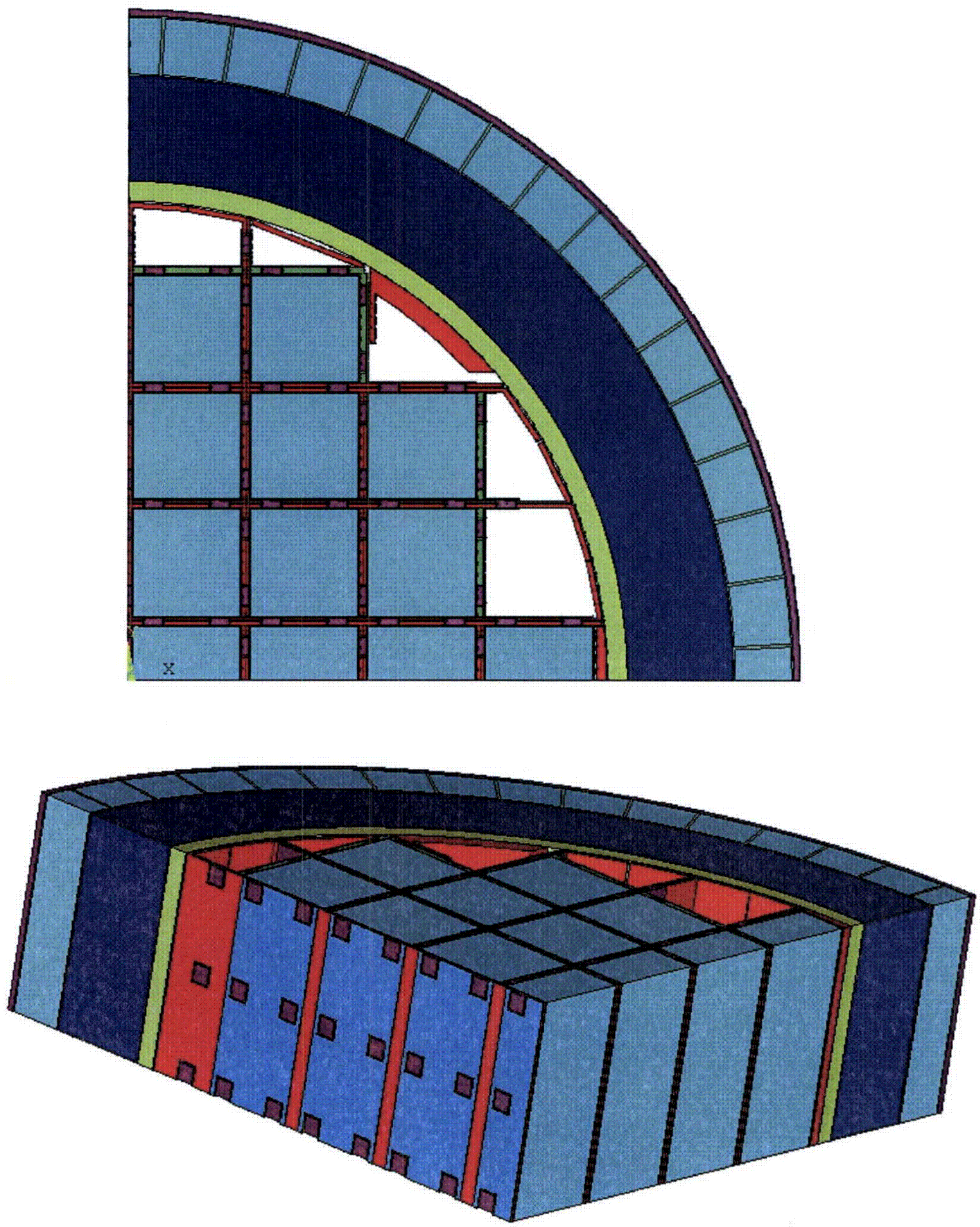


Figure 3-2 FE Model of the TN-40 Transport Cask, Basket Cross Section

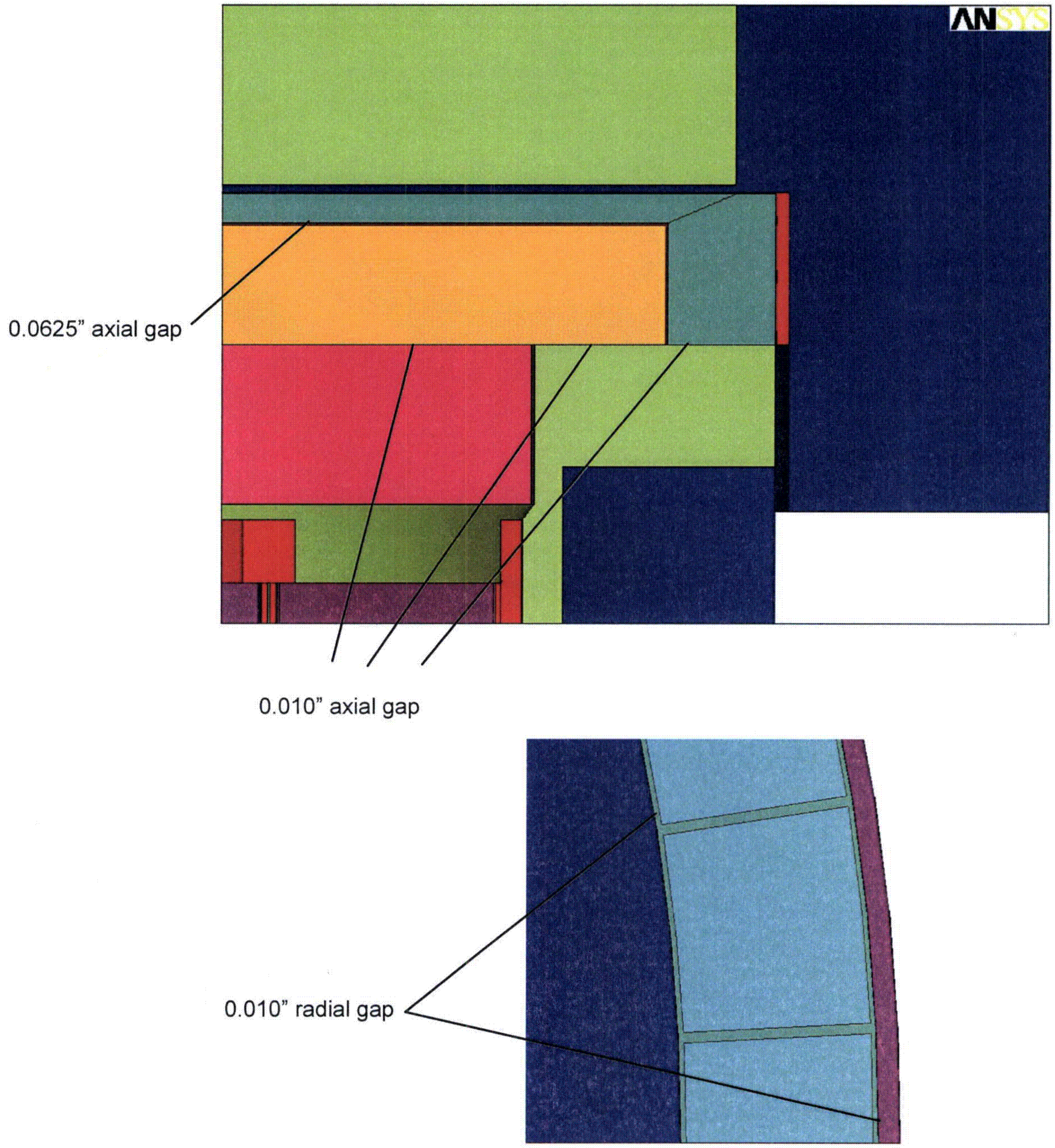


Figure 3-3 FE Model of the TN-40 Transport Cask, Detail of Cask

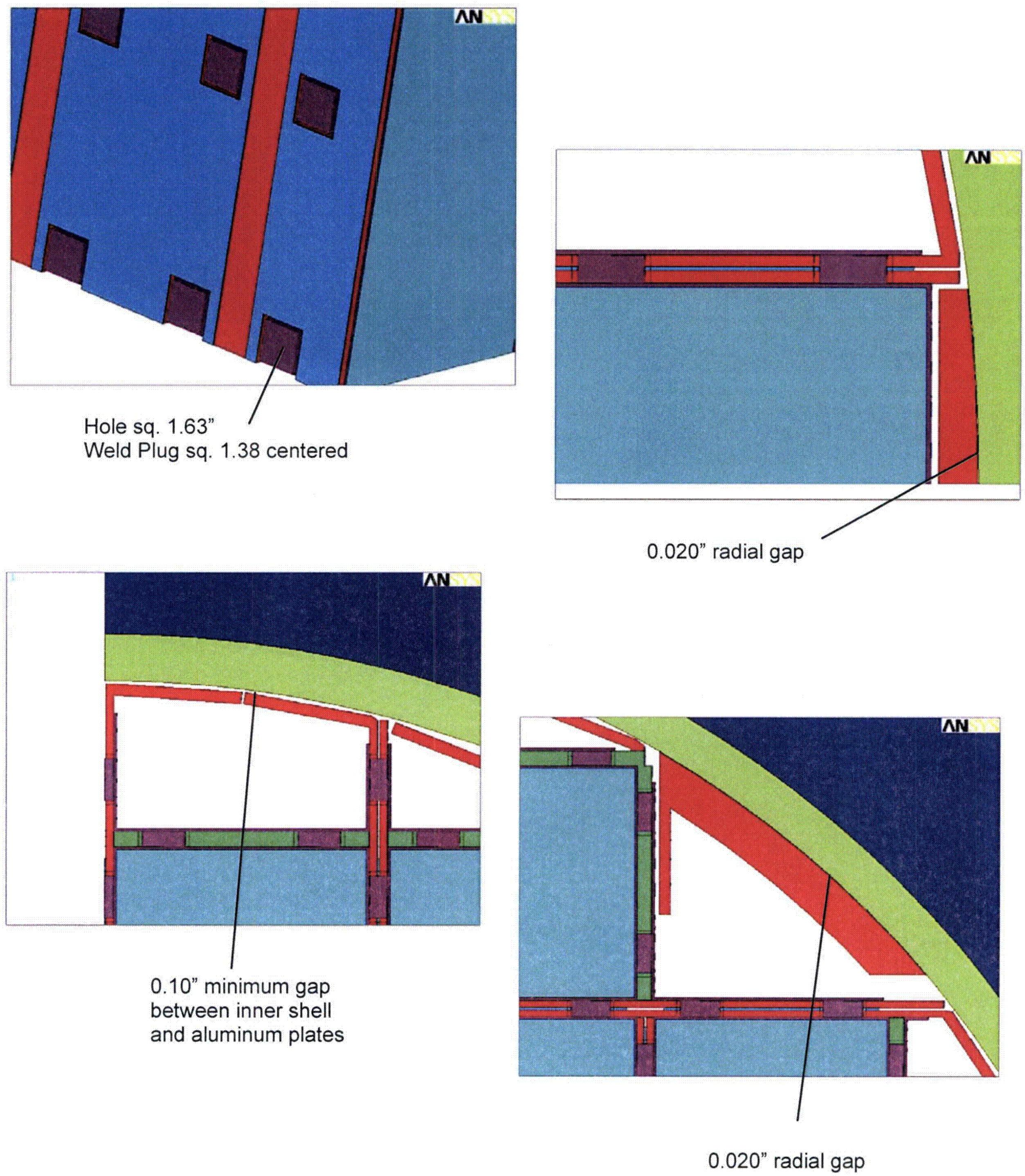


Figure 3-4 FE Model of the TN-40 Transport Cask, Details of Basket

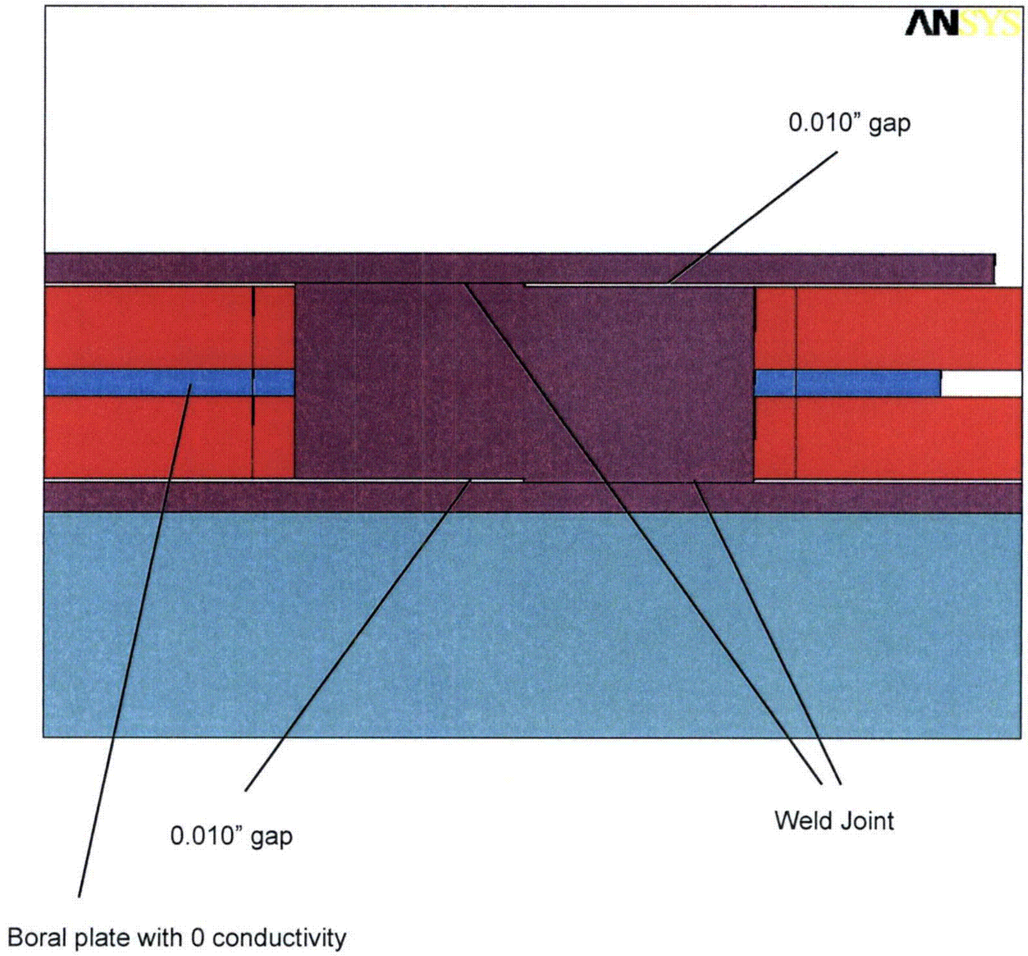
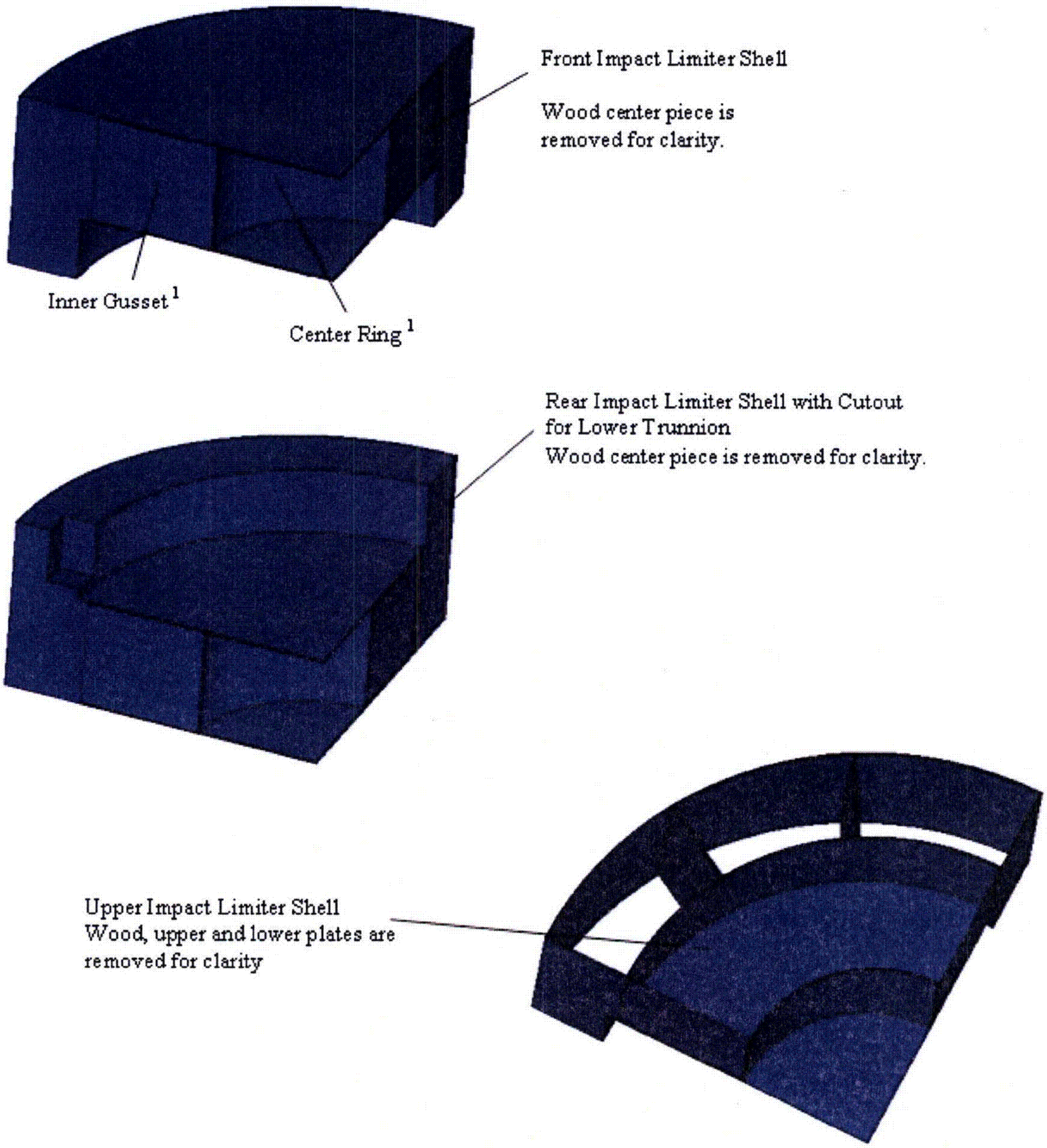


Figure 3-5 FE Model of the TN-40 Transport Cask, Details of Compartment Weld Joint



---

[1] Center ring and inner gussets are not included in the model for normal transport conditions. Theses features are considered only for accident conditions.

Figure 3-6 Detail of the Impact Limiters

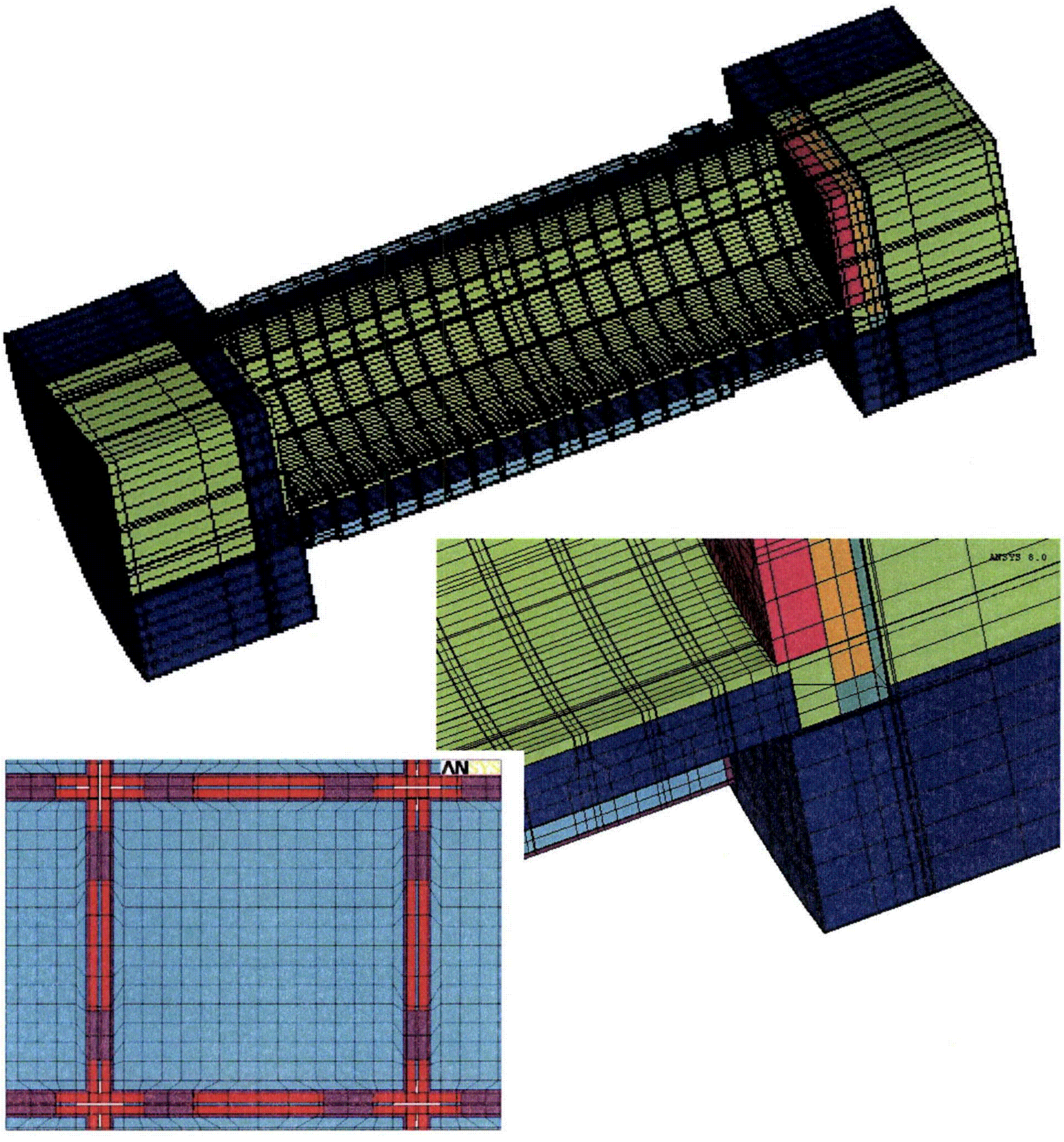


Figure 3-7 Mesh of Finite Element Model

4.0 ASSUMPTIONS AND CONSERVATISM

The following physical gaps are considered in the TN-40 transport cask model based on drawings in reference [3].

- 0.16" gap between the small aluminum rail (item 30, ref. [3]) and basket plates based on note 9, Drawing 10421-71-9, rev. 0, ref. [3])
- 0.09" gap between the conduction plate of the large aluminum rail (item 29, ref. [3]) and basket plates, based on drawings 10421-71-6, rev. 0 and 10421-71-9, rev. 0, ref. [3]

The following contact gaps are considered in the TN-40 transport cask model to bound the heat conductance uncertainty between the components.

- 0.01" gap between each two adjacent basket plates
- 0.01" gap between the weld plugs and the adjacent fuel compartments
- 0.10" minimum gap between the aluminum basket plates (item 20 & 21, ref. [3]) and cask inner shell
- 0.02" radial gap between the aluminum rails (items 22 & 25, ref. [3]) and cask inner shell
- 0.01" axial gap between lid outer plate and the cask flange
- 0.01" axial gap between the lid outer plate and the shield plate
- 0.01" radial gap between the aluminum boxes containing resin and the adjacent shield shell / outer shell
- 0.01" axial gap between the impact limiter spacer and the cask lid
- 0.01" axial gap between the impact limiter spacer and the shell flange
- 0.0625" axial gap between the impact limiter spacer and the front impact limiter
- 0.0625" axial gap between the bottom shield and the rear impact limiter
- 0.125" gap between the bottom shield and the bottom inner plate, identical to geometrical assumptions in [1]

The 0.0625" axial gaps between the impact limiters and the cask components are identical to those used for TN-68 transport application in reference [9], section 3.4.1.2.

A 0.01" gap with conductivity of 0.0243 Btu/hr-in-°F is considered between the inner shell and the shield shell to represent the interference fit between these shells contact. The dimension and the property of this gap are identical to the one considered in reference [1] as basis for thermal analysis of TN-40 storage cask.

For conservatism, no convection or radiation heat transfer is considered within basket. Only gaseous conductance is considered for heat transfer through the gaps.

The cask is transported horizontally. Therefore, the lower half of the packaging is not exposed to solar heat. The model considers only a 90 degree segment of the cask upper half and does not take credit for the heat dissipation from the cooler surfaces of the lower half. This increases the conservatism in the model.

[redacted]

Proprietary Information Withheld in accordance with 10 CFR 2.390.

[redacted]

5.0 MATERIAL PROPERTIES

The material properties used in this analysis are listed below.

5.1 Stainless Steel SA 240, Type 304

SA 240, Type 304 Temperature (°F)	Thermal Conductivity (Btu/hr-in-°F) [6]	Specific heat capacity [1] (Btu/lbm-°F) [6]
70	0.717	0.114
100	0.725	0.114
150	0.750	0.117
200	0.775	0.119
250	0.800	0.121
300	0.817	0.122
350	0.842	0.124
400	0.867	0.126
450	0.883	0.127
500	0.908	0.128
550	0.925	0.129
600	0.942	0.130
650	0.967	0.131
700	0.983	0.132
750	1.000	0.132
800	1.017	0.132
$\rho = 0.29$ lbm/in^3 [16]		

[1] Thermal diffusivity is $\alpha = \frac{k}{\rho\, c_P}$, this equation is used to calculate the specific heat

5.2 Low Alloy Steel SA 203, Gr. E and SA 350, LF3

SA 203, Gr. E SA 350, LF3	Thermal Conductivity	Specific heat capacity [1]
Temperature (°F)	(Btu/hr-in-°F) [6]	(Btu/lbm-°F) [6]
70	1.958	0.102
100	1.967	0.105
200	1.967	0.111
300	1.950	0.116
400	1.925	0.122
500	1.892	0.127
600	1.850	0.132
700	1.800	0.137
800	1.750	0.144
ρ = 0.284 lbm/in^3 [16]		

5.3 Carbon Steel SA 266, Cl. 4, SA 516, Gr. 70, SA 516 Gr. 55, and SA 105

SA 266, Cl. 4 SA 516, Gr. 70 or 55 SA 105	Thermal Conductivity	Specific heat capacity [1]
Temperature (°F)	(Btu/hr-in-°F) [6]	(Btu/lbm-°F) [6]
70	2.925	0.103
100	2.892	0.105
200	2.800	0.112
300	2.692	0.117
400	2.575	0.123
500	2.458	0.127
600	2.333	0.132
700	2.217	0.138
800	2.100	0.145
900	1.983	0.153
1000	1.867	0.162
1100	1.742	0.170
1200	1.625	0.182
1300	1.500	0.204
1400	1.367	0.408
ρ = 0.284 lbm/in^3 [16]		

[1] Thermal diffusivity is $\alpha = \dfrac{k}{\rho \, c_P}$, this equation is used to calculate the specific heat

5.4 Aluminum Alloy 6061

Al 6061	Thermal Conductivity	Specific heat capacity [1]
Temperature (°F)	(Btu/hr-in-°F) [6]	(Btu/lbm-°F) [6]
70	8.008	0.213
100	8.075	0.215
150	8.167	0.218
200	8.250	0.221
250	8.317	0.223
300	8.383	0.226
350	8.442	0.228
400	8.492	0.230
ρ = 0.098 lbm/in^3 [6]		

5.5 Boral Neutron Absorber

As a conservative measure, no thermal property is considered for Boral plates in this analysis. A virtual conductivity of $1\text{x}10^{-8}$ is given to the elements representing Boral in the ANSYS model.

5.6 Solid Neutron Shield (Resin)

ρ = 0.057 lbm/in^3 [1]
k = 0.0083 Btu/hr-in-°F [1]
c_p = 0.311 Btu/lbm-°F [1]

5.7 Helium

Helium	Thermal Conductivity
Temperature (°F)	(Btu/hr-in-°F) [18]
-100	0.0055
-10	0.0064
80	0.0072
260	0.0086
440	0.0102
620	0.0119
800	0.0134
980	0.0148
1160	0.0161

Density and specific heat of gases are very low in comparison to the metallic alloys in the basket and cask. Therefore, no density and no specific heat are considered for gases for conservatism.

[1] Thermal diffusivity is $\alpha = \dfrac{k}{\rho\, c_P}$, this equation is used to calculate the specific heat

5.8 Air

Air Temperature (°F)	Thermal Conductivity (Btu/hr-in-°F) [18]
-100	0.0009
80	0.0013
260	0.0016
440	0.0019
620	0.0022
980	0.0028
1340	0.0033

Density and specific heat of gases are very low in comparison to the metallic alloys in the basket and cask. Therefore, no density and no specific heat are considered for gases for conservatism.

5.9 Wood

From Figure 3-6 of Reference [10], for moisture contents and ranging from 0 to 30% and specific gravities from 0.08 to 0.80, wood conductivities across the grain for both Redwood and Balsa are bounded by the following:

k_{min} = 0.2750 Btu-in/hr-ft^2-°F = 0.0019 Btu/hr-in-°F
k_{max} = 1.950 Btu-in/hr-ft^2-°F = 0.0135 Btu/hr-in-°F

Wood conductivities across the grain from Reference [11], listed below, are also bounded by the above numbers.

Material Type [11]	ID	Conductivity at Room Temperature	
		(cal/s-cm-°C) [11]	(Btu/hr-in-°F)
Wood, Balsa (Across Grain)	BALS1	0.00012	0.0024
Wood, Balsa (Across Grain)	BALS2	0.00020	0.0040
Wood, Cypress (Across Grain)	CYPRS	0.00023	0.0046
Wood, Mahogany (Across Grain)	MAHOG	0.00031	0.0062
Wood, Maple (Across Grain)	MAPLE	0.00042	0.0085
Wood, Norway Pine (Across Grain)	PINEW	0.00036	0.0073
Wood, Oak, Red, Black (Across Grain)	OAKLD	0.00035	0.0071
Wood, Oak, White, Live (Across Grain)	OAKHD	0.00050	0.0101
Wood, Oregon Pine (Across Grain)	PINEL	0.00027	0.0054
Wood, Spruce (Across Grain)	WOOD2	0.00030	0.0060
Wood, Teak (Across Grain)	TEAK	0.00041	0.0083
Wood, Virginia Pine (Across Grain)	PINEV	0.00034	0.0069
Wood, White Fir (Across Grain)	FIRWH	0.00026	0.0052
Wood, White Pine (Across Grain)	PINEA	0.00031	0.0062

The bounding minimum value of 0.0019 Btu/hr-in-°F is used in this analysis. For added conservatism, the wood is given no thermal mass (c_p=0, ρ=0).

6.0 LISTING OF COMPUTER FILES

[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]

Proprietary Information Withheld in accordance with 10 CFR 2.390.

[redacted]	
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]

7.0 DESIGN CRITERIA

To establish the heat removal capability, several thermal design criteria are established for the TN-40 dry storage cask [19]. These are:

- Seal temperatures must be maintained within specified limits to satisfy the leak tight function of transfer cask back filled with helium. A maximum long-term seal temperature limit of 536°F is considered for the Helicoflex seals (double metallic O-rings) in the containment vessel closure lid [9].
- To maintain the stability of the neutron shield resin during normal transport conditions, an allowable temperature range of -40 to 300 ° F (-40 to 149 °C) is set for the neutron shield [9]
- In accordance with 10CFR71.43(g) [7] the maximum temperature of accessible package surfaces in the shade is limited to 185 °F (85 °C).
- A maximum fuel cladding temperature limit of 400 °C (752 °F) is set for the fuel assemblies with an inert cover gas as concluded in Reference [12].
- A temperature limit of 230 °F is considered for wood to prevent excessive reduction in structural properties at elevated temperatures based on [15].

8.0 RESULTS

The temperature distributions are shown in Figure 9-1 for 100°F ambient and in Figure 9-2 for -20°F and -40°F ambient temperatures. The temperature distribution at the cask surface for 100°F and no insolance is shown in Figure 9-3.

The maximum component temperatures are listed in Table 9-1.

9.0 CONCLUSION

The thermal analysis for normal transport concludes that the TN-40 cask design meets all applicable requirements. The maximum temperatures calculated using conservative assumptions are low. The maximum temperature of any containment structural component is less than 251°F (122°C). The maximum seal temperature (195°F, 91°C) during normal transport is well below the 536°F long-term limit specified for continued seal function. The maximum neutron shield temperature is below 300°F (149°C) and no degradation of the neutron shielding is expected. The predicted maximum fuel cladding temperature (495°F / 257°C) is well within allowable fuel temperature limit of 716°F (380°C).

The accessible surface (outer surface of impact limiter) is 114°F under normal transport conditions (ambient 100°F) with solar heat flux. The accessible surface temperature in shade is 106 °F and hence lower than the acceptable limit of 185°F. If the personnel barrier is not used, the cask outer shell temperature is accessible. The analysis shows that without the personnel barrier the maximum accessible cask surface temperature is 208°F and exceeds the limit of 185°F. It concludes that the personnel barrier cannot be removed for transport operation at the maximum heat load of 22kW.

Table 9-1 Maximum Component Temperatures for 22kW Heat Load

Component	T_{max} (°F) @ 100 °F With Insolance	T_{max} (°F) @ 100 °F No Insolance	T_{max} (°F) @ -20 °F No Insolance [1]	T_{max} @ -40 °F No Insolance [1]	Temp Limit (°F)
Fuel Cladding	495	490	401	386	716
Fuel Compartment	444	439	346	330	*
Basket Al-Plate	444	438	346	330	*
Basket Rails	257	243	151	133	*
Cask Inner Shell	251	245	144	127	*
Cask Shield Shell	248	242	140	123	*
Bottom Inner Plate	234	228	126	109	*
Bottom Shield	227	221	119	101	*
Top Shield Plate	192	186	82	64	*
Cask Lid	192	186	81	63	*
Lid Seal	195	189	86	68	536
Solid Neutron Absorber	229	223	120	102	300
Outer Shell	214	208	106	88	*
Wood	224	218	115	97	230
Impact Limiter Surface (accessible surface with personnel barrier)	114	106 [2]	-12	-31	185
Upper Trunnion	191	185	81	63	*
Lower Trunnion	225	219	117	99	*

* The components perform their intended safety function within the operating range

[1] These results are intended for use in structural evaluation

[2] The maximum accessible surface temperature under shade and 100 °F ambient using the personnel barrier is 106 °F. If no personnel barrier is used, the accessible cask surface temperature is 208 °F and exceeds the allowable limit of 185 °F, see Figure 9-3.

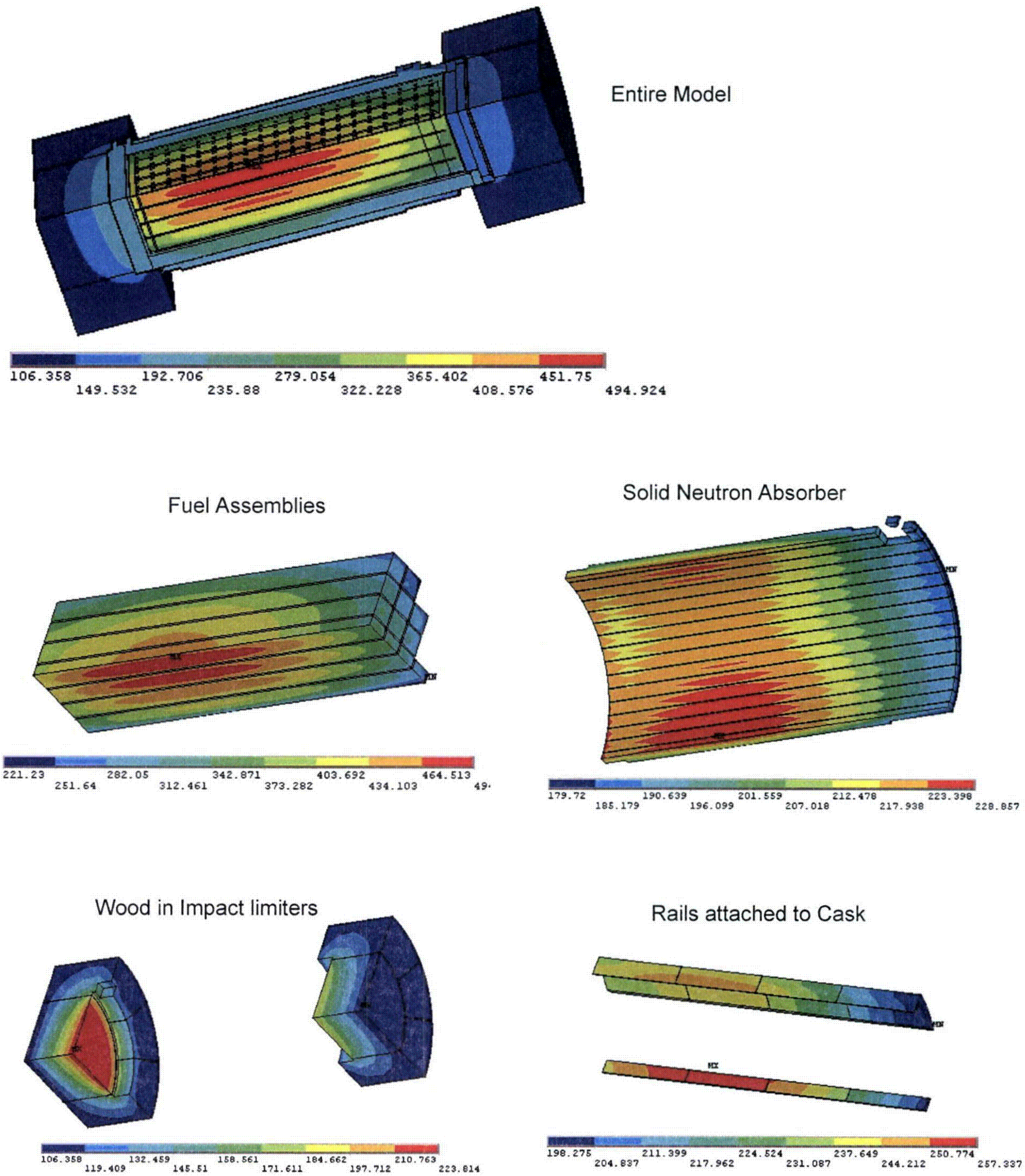


Figure 9-1 Temperature Distributions for Normal Transport Conditions, 100°F

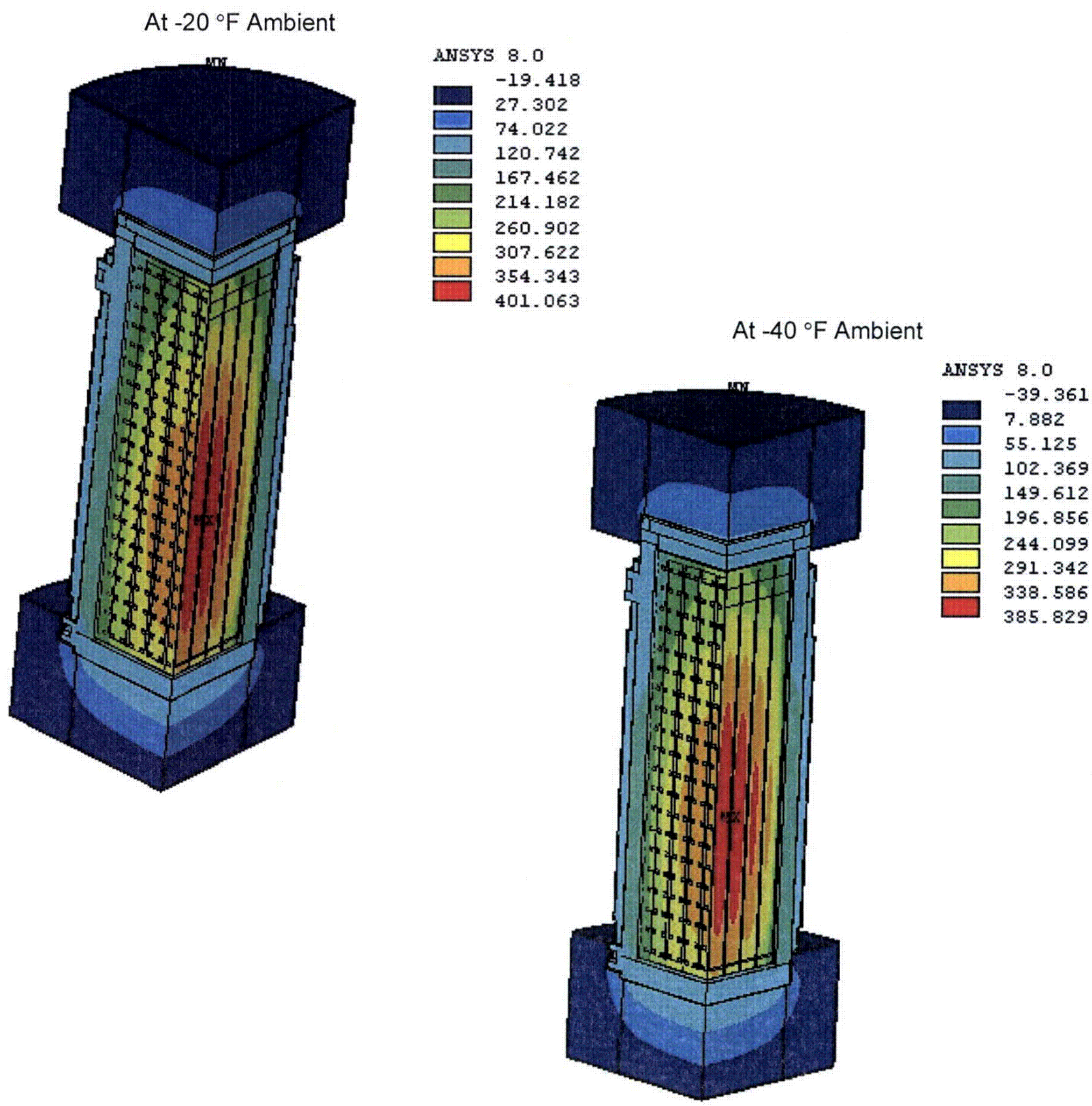


Figure 9-2 Temperature Distribution for Transport Conditions, -20 °F and -40 °F

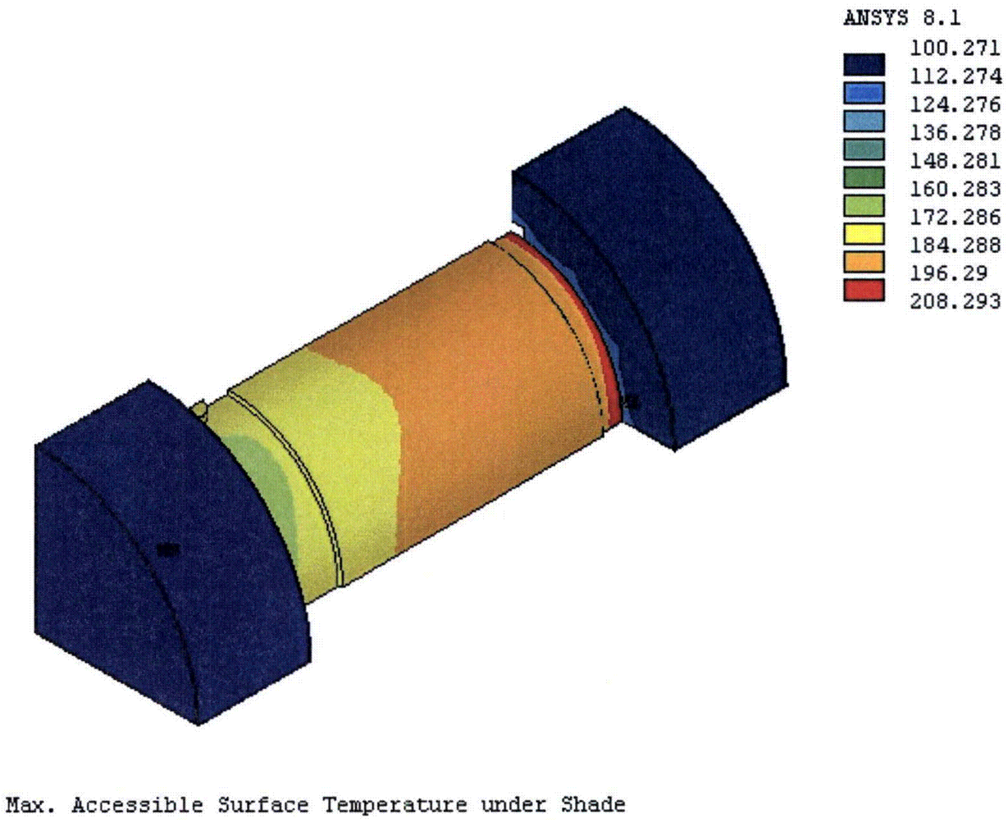


Figure 9-3 Surface Temperature for Transport Conditions, 100 °F and No Insolance

Proprietary Information Withheld in accordance with 10 CFR 2.390.

Proprietary Information Withheld in accordance with 10 CFR 2.390.

Proprietary Information Withheld in accordance with 10 CFR 2.390.

11.0 APPENDIX B TOTAL HEAT TRANSFER COEFFICIENTS

The outer surface of TN-40 transport cask dissipates heat to the ambient via free convection and radiation. Total heat transfer coefficient is defined as:

$$H_t = h_r + h_c$$

where,

h_r = radiation heat transfer coefficient
h_c = free convection heat transfer coefficient

The radiation heat transfer coefficient, h_r, is given by the equation:

$$h_r = \varepsilon\, F_{12} \left[\frac{\sigma (T_1^4 - T_2^4)}{T_1 - T_2} \right] Btu/hr\text{-}ft^2\text{-}^\circ F$$

where,

ε	= surface emissivity
F_{12}	= view factor from surface to ambient
σ	= 0.1714×10^{-8} Btu/hr-ft^2-R^4
T_1	= surface temperature, R
T_2	= ambient temperature, R

The following equations from reference [13] are used to calculate the free convection coefficients.

<u>For horizontal cylinders:</u>

$$h_c = \frac{Nu\, k}{D}$$ with

D = diameter of the horizontal cylinder
k = air conductivity

$Nu^T = 0.772\, \overline{C}_l\, Ra^{1/4}$ $\quad \overline{C}_l = 0.515$ for gases [13]

$Nu_l = \dfrac{2f}{\ln(1 + 2f / Nu^T)}$ Nusselt number for fully laminar heat transfer with $f = 1 - \dfrac{0.13}{(Nu^T)^{0.16}}$

$Nu_t = \overline{C}_t\, Ra^{1/3}$ Nusselt number for fully turbulent heat transfer with

$\overline{C}_t = 0.14 \left(\dfrac{1 + 0.0107\,\Pr}{1 + 0.01\,\Pr} \right)$ for horizontal cylinders [13]

$$Nu = \left[(Nu_l)^m + (Nu_t)^m\right]^{1/m} \quad with \quad m = 10 \quad for \quad 10^{-10} < Ra < 10^7$$

$$Ra = Gr\,\mathrm{Pr} \quad ; \quad Gr = \frac{g\,\beta(T_w - T_\infty)\,D^3}{\nu^2}$$

<u>For vertical flat plates:</u>

$$h_c = \frac{Nu\,k}{L}$$ with

L = height of the vertical plate
k = air conductivity

$$Nu^T = \overline{C}_l\,Ra^{1/4} \qquad \overline{C}_l = 0.515$$ for gases [13]

$$Nu_l = \frac{2.0}{\ln(1 + 2.0/Nu^T)}$$ Nusselt number for fully laminar heat transfer

$$Nu_t = C_t^V\,Ra^{1/3}$$ Nusselt number for fully turbulent heat transfer with

$$C_t^V = \frac{0.13\,\mathrm{Pr}^{0.22}}{(1 + 0.61\,\mathrm{Pr}^{0.81})^{0.42}}$$

$$Nu = \left[(Nu_l)^m + (Nu_t)^m\right]^{1/m} \quad with \quad m = 6 \quad for \quad 0.1 < Ra < 10^{12}$$

$$Ra = Gr\,\mathrm{Pr} \quad ; \quad Gr = \frac{g\,\beta(T_w - T_\infty)\,L^3}{\nu^2}$$

[redacted]

Proprietary Information
Withheld in accordance
with 10 CFR 2.390.

Table 11-1 Thermal Properties of Air [13]

Specific Heat (kJ/kg-K)	Dynamic Viscosity (N-s/m^2)	Conductivity (W/m-K)
$c_p = \sum \left[A(N)T^N\right]$	$\mu = \sum \left[B(N)T^N\right]$	$k = \sum \left[C(N)T^N\right]$
A(0)= 0.103409E+1 A(1)= -0.2848870E-3 A(2)= 0.7816818E-6 A(3)= -0.4970786E-9 A(4)= 0.1077024E-12	For 250≤ T < 600 K B(0)= -9.8601E-1 B(1)= 9.080125E-2 B(2)= -1.17635575E-4 B(3)= 1.2349703E-7 B(4)= -5.7971299E-11 For 600≤ T < 1050 K B(0)= 4.8856745 B(1)= 5.43232E-2 B(2)= -2.4261775E-5 B(3)= 7.9306E-9 B(4)= -1.10398E-12	C(0)= -2.276501E-3 C(1)= 1.2598485E-4 C(2)= -1.4815235E-7 C(3)= 1.73550646E-10 C(4)= -1.066657E-13 C(5)= 2.47663035E-17